Land Use/Land Cover Map of the Central Facility of ARM in the Southern Great Plains Site Using DOE's Multi-Spectral Thermal Imager Satellite Images

S. E. Báez Cazull
Pre-Service Teacher Program
University of Puerto Rico
Rio Piedras, Puerto Rico

A. Cialla
Brookhaven National Laboratory
Department of Environmental Sciences
Upton, New York

Introduction

The Atmospheric Radiation Measurement (ARM) Program is a multi-laboratory, interagency program that was created with funding from the U.S. Department of Energy (DOE). The ARM Program is part of DOE's effort to resolve scientific uncertainties about global climate change with a specific focus on improving the performance of general circulation models (GCMs) used for climate research and prediction. The ARM Program established and operates field research sites, called Cloud and Radiation Testbeds (CARTs), in several climatically significant locations; Southern Great Plains (SGP), Tropical Western Pacific, and the North Slope of Alaska. Scientists collect and analyze data obtained over extended periods of time from a large array of instruments to study the effects and interactions of sunlight, radiant energy, and clouds on temperatures, weather, and climate. (http://www.arm.gov/docs/about.html)

This energy balance is affected by soil moisture, land surface, and plant growth. Land Use/Land Cover maps provide information about these properties and they can be used as ancillary information for interpreting data from instruments measuring energy balance. Other uses of Land Cover maps include studies in soil moisture and research on carbon fluxes affected by the vegetation.

Multi-spectral satellite imagery is one of the most useful sources to collect valuable land surface information. Scientists use multi-spectral remotely sensed images because they can distinguish features by their spectral and spatial properties and more information can be obtained by looking at the spectral reflectance of an object. Also, it is less time intensive than field based measurements.

For this project, the satellite images used were from DOE's multi-spectral thermal imager (MTI) (http://nis-www.lanl.gov/nis-projects/mti/). These MTI images contain 15 spectral bands, the first four bands at a 5 m ground resolution and the rest of the bands at 20 m resolution. The three images were taken in June (Figure 1a), August (Figure 1b), and October (Figure 1c) of 2000, covering the ARM's

Central Facility (CF) site, near Lamont, Oklahoma. The first four bands with a finer resolution were used for this project. The bands ranged from 0.42 to 0.52 mm (Blue), 0.52 to 0.60 mm (Green), 0.62 to 0.68 mm (Red), and 0.76 to 0.86 mm (VNIR).

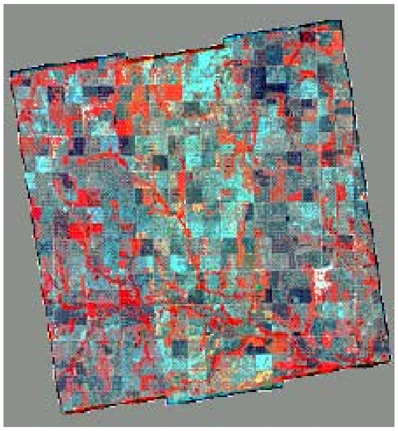

Figure 1a. June image

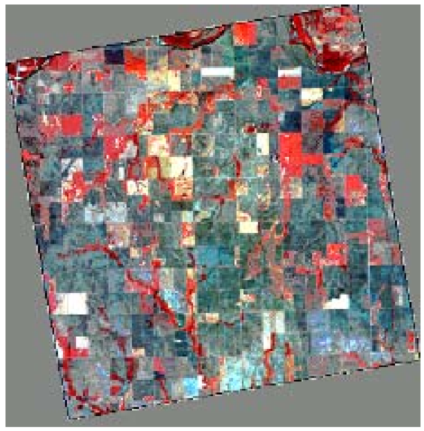

Figure 1b. August image

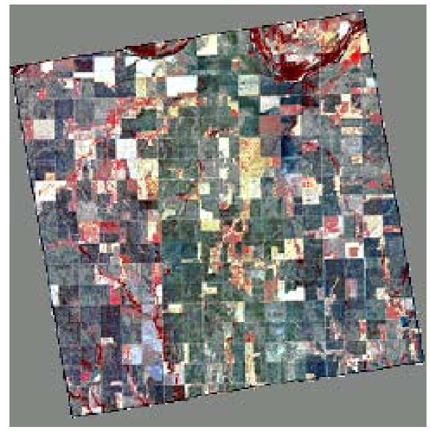

Figure 1c. October image

With spectral information from each of the bands in each seasonal image a Land Use/Land Cover map classification was derived using ERDAS Imagine image processing software. Vegetation indices and Principal Components Analysis, along with ancillary data including Digital Orthophoto Quarter Quadrangles (DOQQs), other land maps, personal communications, and harvest tables were used to label the classes and create the final Land Use/Land Cover map.

Georeference

The 5-m resolution MTI images were georeferenced to USGS DOQQs of 1-m resolution in UTM Projection. Approximately 21 Ground Control Points (GCPs) were selected, most of them road intersections. A resampling was conducted using bilinear interpolation.

Methods

Multi-Temporal Image Cube

The first four bands of the three multi-spectral images (see Figures 2a,b,c) were stacked into one single image. The three images covered slightly different areas, so an intersected area of the three images was selected and covers a 9.5 km x 9 km area. This stacked image "cube" is more useful because all the information from crop changes across the season is included in the image. Since each image contains information for four spectral bands (NIR, Red, Green, and Blue), the output image has 12 bands, four bands for each image. (Figure 2a).

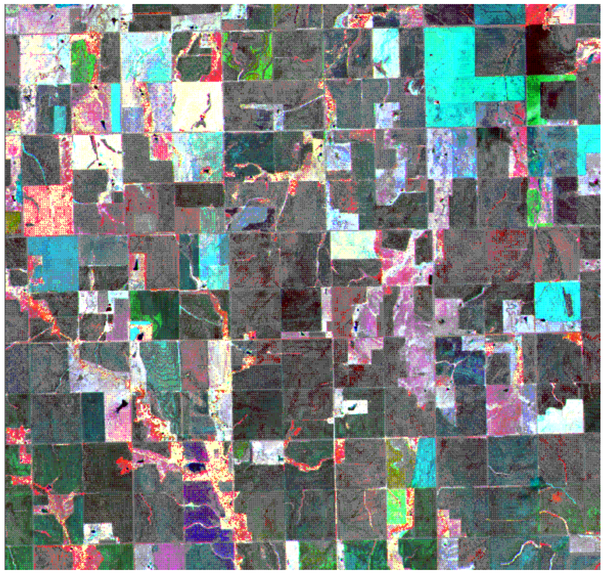

Figure 2a. Multi-temporal image

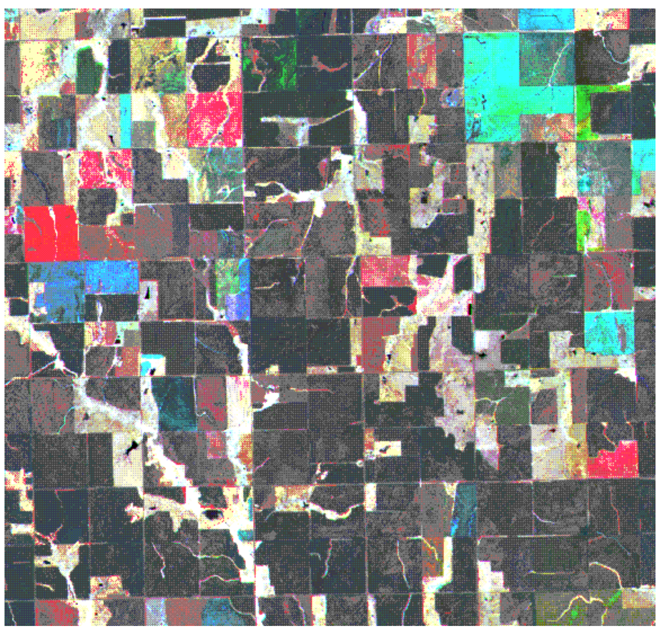

Figure 2b. Multi-temporal NDVI image

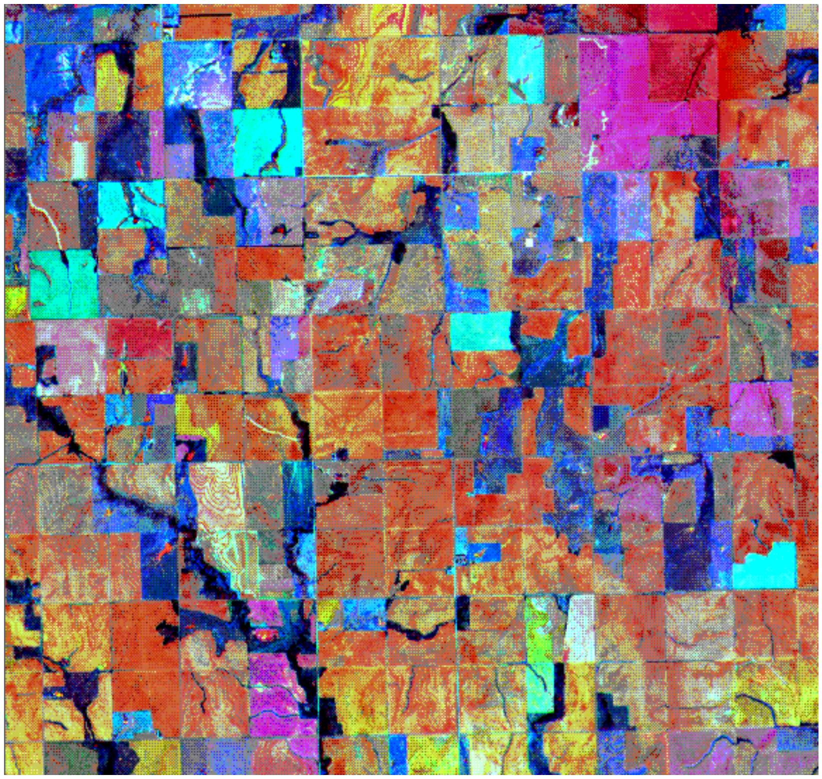

Figure 2c. Multi-temporal NDVI-PCA image cube

Creation of Vegetation Indices

Next step was to create a Normalized Difference Vegetation Index (NDVI) image for each of the MTI images (Figures 3a,b,c). NDVI was calculated by subtracting the Red band from the VNIR band and dividing it by the sum of the VNIR band and the Red band (NDVI = (VNIR - Red)/(VNIR + Red). The new image differentiates between vegetation and non-vegetation. Looking at the true color images, the

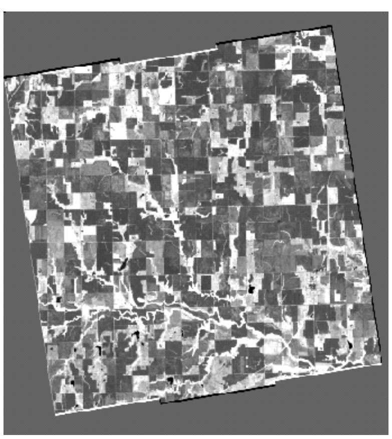

Figure 3a. June NDVI image

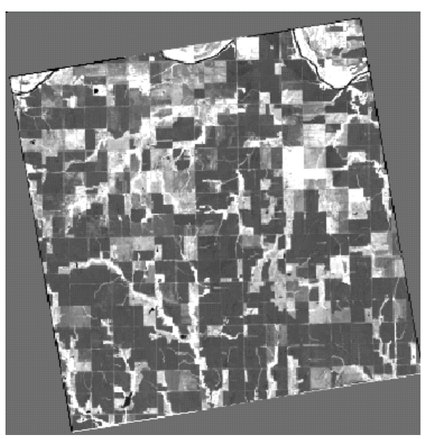

Figure 3b. August NDV image

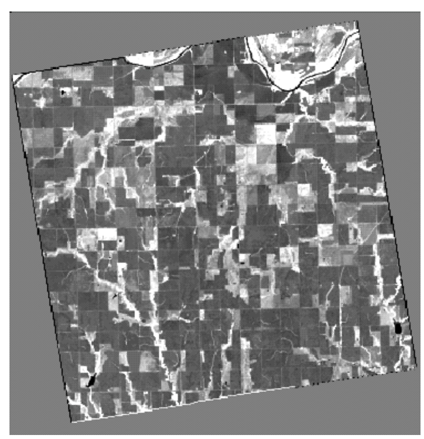

Figure 3c. October NDV image

NIR band, and at the NDVI images was useful to distinguish the vegetated areas and the soil areas. These single date NDVI images were added to the multi-temporal image cube. This multi-temporal plus NDVI image cube contains 15 bands (Figure 2b).

Analysis of Principal Components Analysis Images

Principal Components Analysis (PCA) was performed on each of the three MTI images to produce three PCA images (Figures 4a,b,c). Each one of these PCA images contains information in four bands. The eigenvalues and eigenvectors of the PCA were analyzed together with the variance and covariance. These values were used to create a table of factor loadings, which give information on the intensity, greenness, wetness, and thermal factors of the images.

These PCA images were added to the multi-temporal plus NDVI image cube to get a multi-temporal plus NDVI plus PCA image cube with 27 bands of information (Figure 2c).

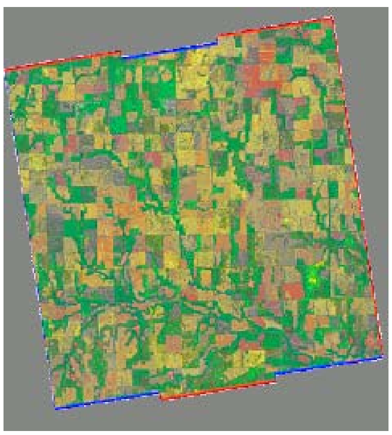

Figure 4a. June PCA image

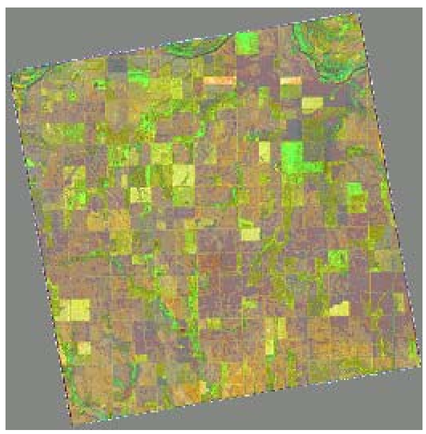

Figure 4b. August PCA image

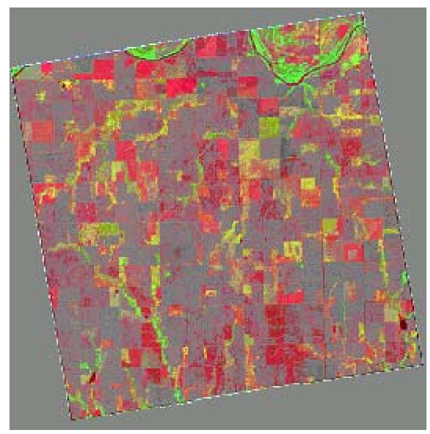

Figure 4c. October PCA image

Classification of the Multi-Temporal-NDVI-PCA Image Cube

This image was the input file for an unsupervised classification using the Iterative Self-Organizing Data Analysis Technique (ISODATA) algorithm. Twenty-five classes using a convergence threshold of 95 were created.

To interpret the 25 classes of the multi-temporal plus NDVI plus PCA image cube into 14 generalized classes, different sources of data were used:

- The 1997 document for the U.S. Department of Agriculture of the SGP Hydrological Experiment containing a 13-class land cover map was used as a reference for ground truth data. This land cover map was developed by using Landsat TM image with a resolution of 30 m.
- Tables of the usual planting and harvesting dates for U.S. Field Crops of December 1997.
- Personal communications with staff and researchers at the SGP CF site.

- Information from the true color and false color images, NDVI, and PCA images.
- Maps and pictures of the surroundings of the CF.

Results and Discussion

A Land Use/Land Cover map with 14 classes was created using the combined multi-temporal plus NDVI plus PCA image. The seasonal images plus the vegetation indices plus the principle components analyses provided the most information to perform the computer classification. The 14 class labels reflect a seasonal land cover class rather than a static land cover class. Some of the classes were very difficult to determine because most of them had a cropland "shape" (1/4 square mile plots) but no vegetation present. These classes were named fallow because it was almost impossible to determine the kind of crop without looking at the vegetation. The classes named fallow wheat, fallow legume, and small grains were determined based on the SGP Land Cover map of 1997. Pasture, grass, and hay were classified by looking at the NDVI images, which indicated some vegetation though not very strong. This could also mean that the vegetation is stressed. The few croplands that were classified were named winter wheat and feedcrop. Winter wheat is usually planted in October and is harvested in June. This winter wheat cropland class showed healthy and abundant vegetation in June, almost no vegetation in August and in October, indicating probable wheat stubble. The feedcrop class near the CF was verified by staff from the CF and is actually milo. Bare, sandy soil and buildings were grouped in the same class because of their spectral similarities. A few buildings are present in the image and they are all located near the CF and on farms. No urban areas exist on the images and the rest is bare and sandy soil. Forest and water were easily determined by their strong spectral and spatial characteristics in the NDVI, PCA, near infrared (NIR), and true color images. While pasture/grass/hay, bare soil/buildings, and fallow were the classes with the most confusion, due to their similar spectral characteristics.

This final classification could be enhanced in the future. There were other spectral bands within the MTI images that were not incorporated. Adding other spectral bands such as a mid-infrared band, even at the coarser resolution of 20 m, may have potentially helped to distinguish additional features. Also, the MTI sensors and their products have only been collected since 2000. There are currently some problems with calibrations of the three sensors, which make up an image. This calibration problem appears as a wide stripe through the center of each image. It is possible that some features were split into two different classes along the line instead of being grouped as one class. However, in this project there appears to be little evidence of this. (Researchers at Los Alamos National Laboratory are currently working on calibration algorithms.)

It is noticeable that very little vegetation is present in the final image. With only a few exceptions (feedcrop, winter wheat, and forest), the earliest seasonal image (June) had the largest amount of vegetation. This would not be expected in a normal growing season. There were a few crops planted that year but they seemed to be stressed. From these images, it can be deduced that it was a very hot and dry summer. Staff of the CF corroborated this information. Knowing the fact that it was hot and dry, that the soil moisture was very low, and that the vegetation was stressed has many implications for studies on energy balance.

Conclusions and Future Directions

Satellite images provide rapid and continuous, spectral and spatial information of the land surface. Land use/land cover maps are derived from satellite images for a meaningful interpretation of the data provided by the images that could be very beneficial for studies on land surface, mineral composition, vegetation, and soil moisture. This study produced a Land Use/Land Cover map of the area surrounding the CF site of the ARM Program (Figure 5).

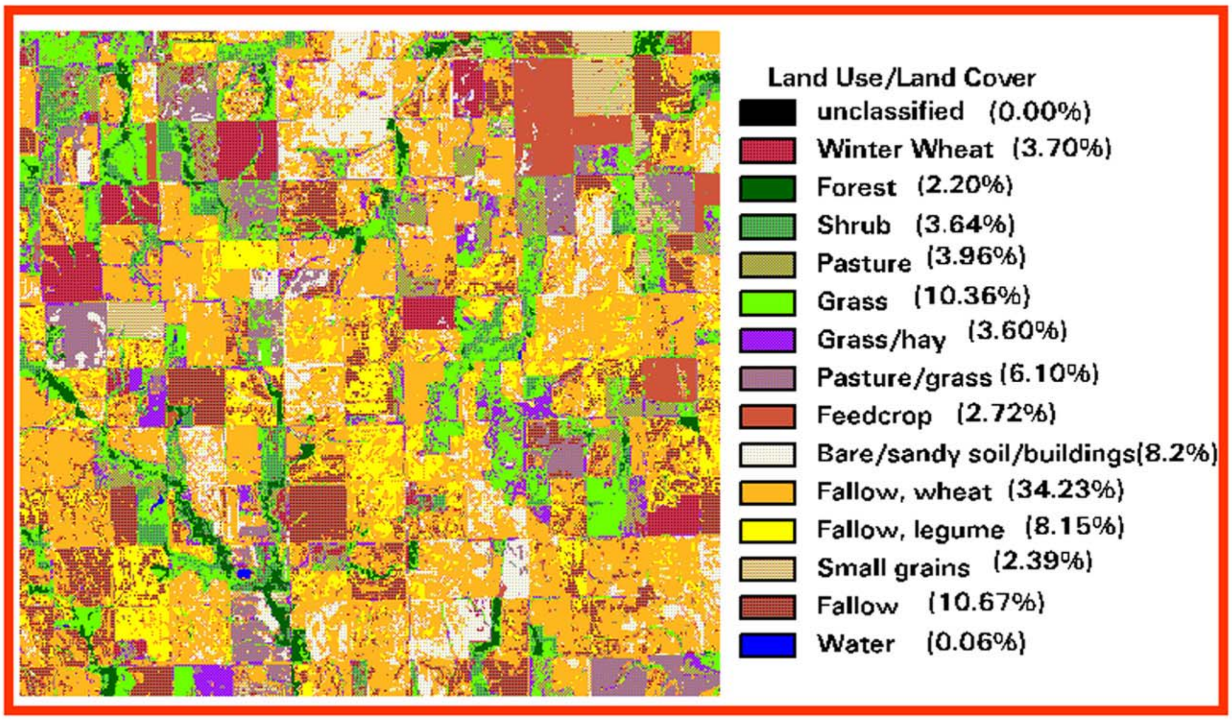

Figure 5. Land Use/Land Cover Map of the CF of ARM Program in the SGP

To improve this Land Use/Land Cover map additional ground truth data for 2000 will be needed. The primary limitation of this project is that the ground truth data available ranged from 1995-1997, or earlier. These datasets are good for distinguishing land types that do not move from year to year (e.g., forest and water) and for georeferencing the image, as with the DOQQs. They are not as useful for distinguishing crop types when crop plantings could change yearly, and planting decisions could change from start of the season to end, depending on the weather conditions.

The resolution of the MTI images is quite good, both spatially and spectrally. Other land use/land cover maps of the areas were based on the coarser spatial resolution of Landsat TM. There is great potential for developing spectral signatures for individual crops in this area with the proper ground truthing. The area could then be expanded to the other SGP ARM experimental sites for the most benefit to scientists working on the ARM program, as well as other researchers interested in energy and land studies in the SGP.

Acknowledgments

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